Optical fibre Bragg grating recorded in TOPAS cyclic olefin copolymer

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We report on the inscription of a fibre Bragg grating into a microstructured polymer optical fibre fabricated from TOPAS cyclic olefin copolymer. This material offers two important advantages over poly (methyl methacrylate), which up to now has formed the basis for polymer fibre Bragg gratings: TOPAS has a much lower water affinity and has useful properties for biosensing. The grating had a Bragg wavelength of 1569nm and a temperature sensitivity of -36.5±0.3 pm/°C.

Introduction: Over the last twenty years, silica fibre Bragg grating (FBG) sensor technology has been developed to the point where it is now mature enough to find commercial application in a variety of fields, such as structural health monitoring and down-hole sensing for the oil and gas industry. Grating sensors in polymer optical fibre (POF) have been studied for about 10 years [1], but remain much less well developed. Nevertheless there appear to be good reasons for pursuing that development due to the rather different properties of POF compared to silica, especially its much lower Young's modulus [2] and its ability to survive much higher strains [3].

Research to date on POF gratings has essentially involved just one material, poly (methyl methacrylate) (PMMA), with fibres either being fabricated entirely out of this material, in the case of microstructured fibres [4], or based on this

material with the addition of dopants in the fibre core, in the case of step index fibres [5]. However there are many other transparent polymers with properties that might be utilised for sensors, if they can be drawn into fibre and if they possess a suitable photosensitivity to permit grating inscription. One example is TOPAS cyclic olefin copolymer. Unlike PMMA, this material is chemically inert, but it has been shown to be possible to fabricate localised biosensors by treatment with antraquinon followed by UV activation [6-7]. Furthermore, TOPAS has a much reduced affinity for water compared to PMMA [8]. which may prevent the cross-sensitivity to humidity that is an issue for PMMA based FBGs [9]. Interestingly, Topas is also an ideal material for terahertz fibres, because it becomes transparent with strongly reduced material dispersion in the terahertz frequency range [10].

Photosensitivity has been reported in some early TOPAS fibre [11], but the results obtained then were not very reproducible, the grating was visible in transmission but curiously not in reflection and temperature testing suggested a surprisingly large and positive Bragg wavelength sensitivity. In this paper we report on the successful and repeatable inscription of FBGs in microstructured fibre fabricated from TOPAS, and characterise the temperature response of the devices, which we now repeatedly and reliably measure to be negative.

Experimental: A solid cylindrical preform of TOPAS 8007-F-04 of diameter 6 cm was drilled with two rings of 3 mm air holes to provide light guidance and drawn down to an all TOPAS fibre in a two stage process. The resulting fibre had a diameter of 270 μm, a hole pitch of 8.5 μm and a hole diameter of 3.8 μm and was single mode at 1550nm; see Fig. 1. Grating inscription was

carried out using a 325nm HeCd laser commonly used for grating fabrication with PMMA based fibre (Kimmon IK3301R-G). The fibre was mounted horizontally in a v-groove for support and the beam focussed down from above onto the fibre using a cylindrical lens of focal length 10cm. The UV light passed through a phase mask of period 1034.2 nm optimised for 325 nm light and supported directly on the fibre. The growth of the grating was monitored by butt coupling an angle cleaved single-mode silica fibre lead from a 2x2 coupler to the TOPAS fibre, which had been cleaved using a razor blade at room temperature. The grating was illuminated using a broadband light source (Thorlabs, Broadband ASE light source) and monitored on an optical spectrum analyser (HP86142A). A small amount of index matching gel was used to reduce Fresnel reflections from the end of the silica fibre. With a beam power of 30 mW approximately 45 minutes were required for the gratings to reach saturation, see Fig. 2. The reflection spectrum from the 1.8 mm long grating is shown in Fig. 3; the Bragg wavelength is 1567.9 nm and the bandwidth (full width at half maximum) is 0.75 nm.

TOPAS has the same high attenuation as PMMA in the 1550 nm spectral region, which limits practical fibre lengths to around 10 cm. Consequently, following inscription, the grating was glued to the end of a single mode silica fibre lead to facilitate temperature testing. The grating was placed in an environmental chamber (Sanyo Gallenkamp) with the humidity held at 55% to remove any possibility of this influencing the measurements. The temperature was varied in the range 20 to 35 °C and the results shown in Fig. 4. From the data, the temperature sensitivity is obtained as -36.5±0.3 pm/°C. This value is not very different from that obtained with PMMA based FBGs at a similar

wavelength (-43 pm/°C [12]) and confirms that the preliminary data obtained from the first TOPAS FBG showing a positive wavelength shift was in error [11]. Whilst the data presented in this paper come from one grating, several were fabricated in the TOPAS fibre, with all exhibiting similar behaviour.

One disadvantage of TOPAS compared to PMMA is its glass transition temperature of 78°C [8], which is almost 30°C less than that of typical PMMA. This provides an upper limit on the useable temperature range.

Conclusion: We have proven definitively that fibre Bragg grating sensors can be reliably recorded in fibres fabricated from TOPAS cyclic olefin copolymer. For the first time this permits the development of POF based strain sensors that should not suffer from significant cross-sensitivity to humidity and also aids the development of novel grating based polymer fibre biosensors.

References

1 Xiong, Z., Peng, G., Wu, B., and Chu, P.: 'Highly tunable Bragg gratings in single-mode polymer optical fibers', IEEE Photonics Technology Letters, 1999, 11, (3), pp. 352-354

2 Brandrup, J.: 'Polymer Handbook' (Wiley, 1999. 1999)

3 Aressy, M.: 'Manufacturing optimisation and mechanical properties of polymer optical fibre'. MPhil, Birmingham University, 2006

4 Dobb, H., Webb, D.J., Kalli, K., Argyros, A., Large, M.C.J., and van Eijkelenborg, M.A.: 'Continuous wave ultraviolet light-induced fiber Bragg

gratings in few- and single-mode microstructured polymer optical fibers', Optics Letters, 2005, 30, (24), pp. 3296-3298

5 Peng, G.D., and Chu, P.L.: 'Polymer optical fiber photosensitivities and highly tunable fiber gratings', Fiber and Integrated Optics, 2000, 19, pp. 277-293

6 Emiliyanov, G., Jensen, J.B., Bang, O., Hoiby, P.E., Pedersen, L.H., Kjaer, E.M., and Lindvold, L.: 'Localized biosensing with Topas microstructured polymer optical fiber', Optics Letters, 2007, 32, (5), pp. 460-462

7 Emiliyanov, G., Jensen, J.B., Bang, O., Hoiby, P.E., Pedersen, L.H., Kjaer, E.M., and Lindvold, L.: 'Localized biosensing with Topas microstructured polymer optical fiber: Erratum', Optics Letters, 2007, 32, (9), pp. 1059

8 www.topas.com

9 Zhang, C., Zhang, W., Webb, D.J., and Peng, G.D.: 'Optical fibre temperature and humidity sensor', Electronics Letters, 2010, 46, (9), pp. 643-644

10 Nielsen, K., Rasmussen, H.K., Adam, A.J.L., Planken, P.C.M., Bang, O., and Jepsen, P.U.: 'Bendable, low-loss Topas fibers for the terahertz frequency range', Optics Express, 2009, 17, (10), pp. 8592-8601

11 Webb, D.J., Kalli, K., Zhang, C., Komodromos, M., Argyros, A., Large, M., Emiliyanov, G., Bang, O., and Kjaer, E.: 'Temperature sensitivity of Bragg gratings in PMMA and TOPAS microstructured polymer optical fibres - art. no. 69900L'. Photonic Crystal Fibers II2008 pp. L9900-L9900

12 Webb, D.J., and Kalli, K.: 'Polymer fibre Bragg gratings', in Cusano, A. (Ed.): 'Fiber Bragg Grating Sensors: Thirty Years from Research to Market' (Bentham eBooks, 2010)

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Figure captions:

Fig. 1 Microscope image of a cleaved end face of TOPAS fibre of diameter 287 μm. Inset: magnified view of core region.

Fig. 2 Growth in reflectivity as a function of time during grating inscription. The background noise level is around -77 dBm.

Fig. 3 Reflection spectrum from FBG in TOPAS fibre.

Fig. 4. Thermal response of TOPAS FBG.

Figure 1

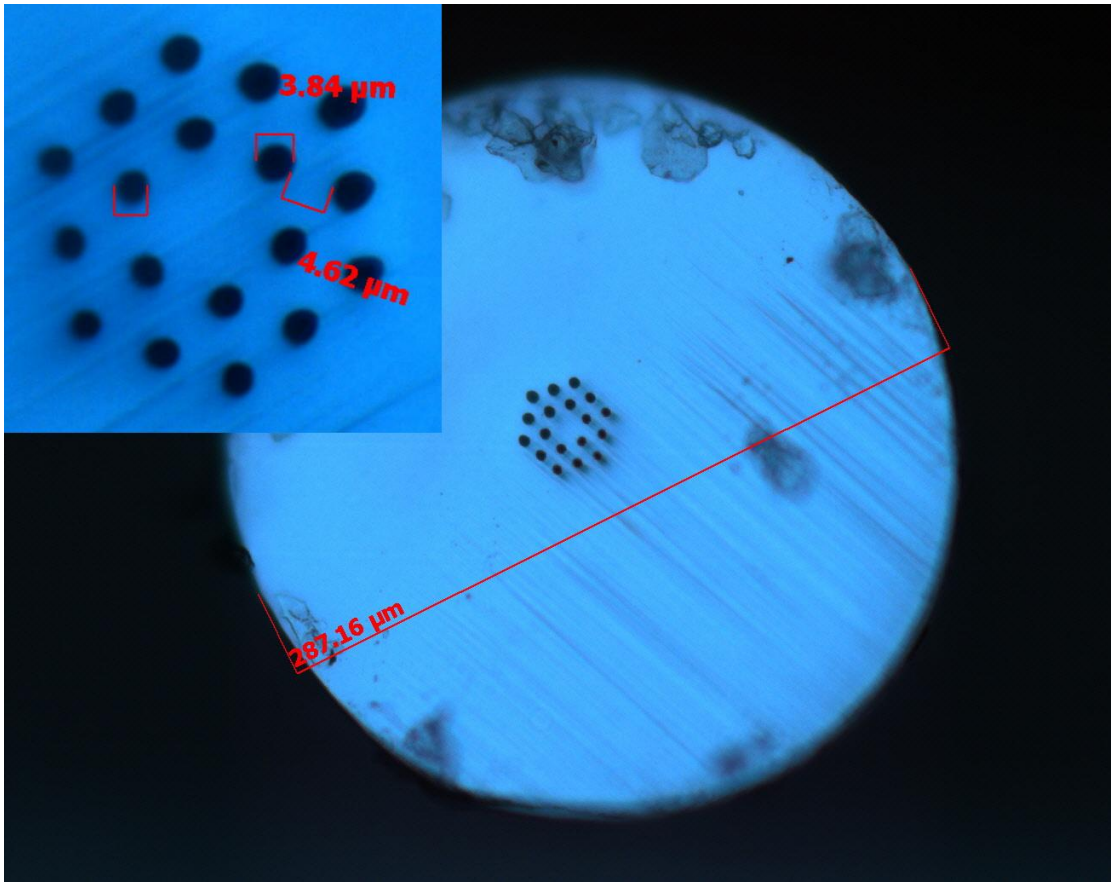


Figure 2

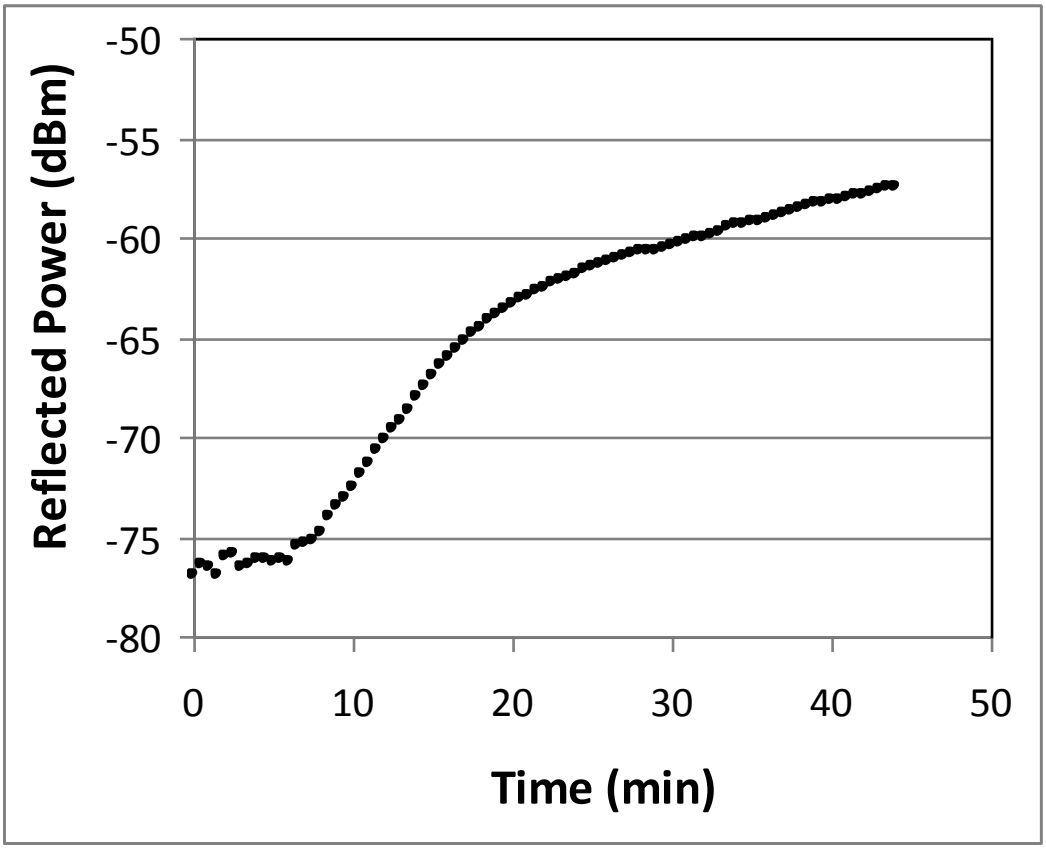


Figure 3

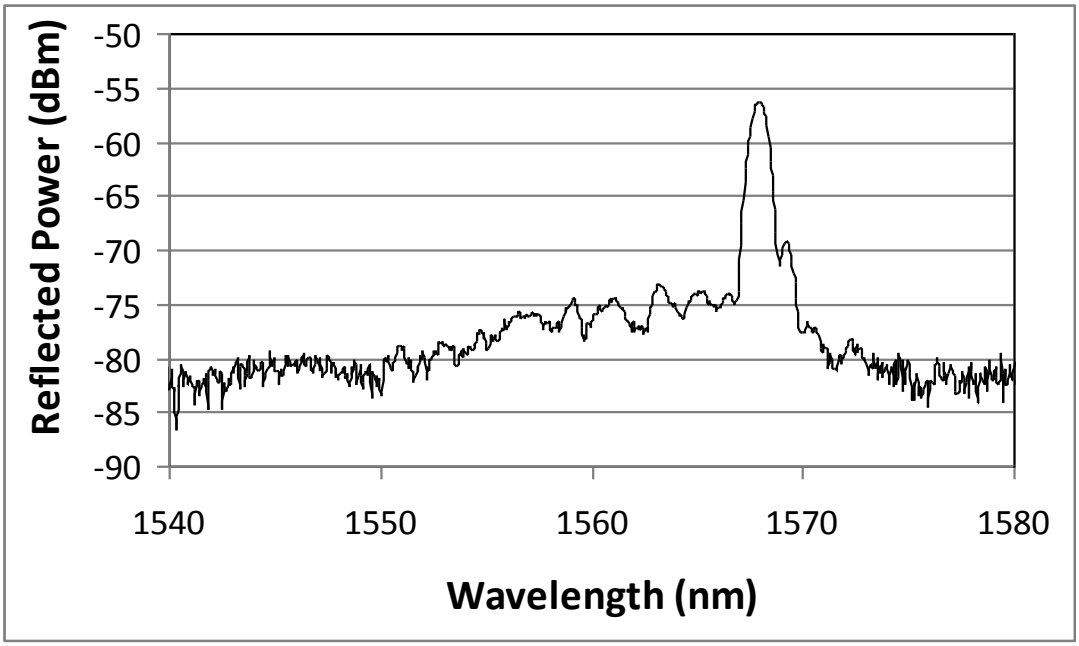
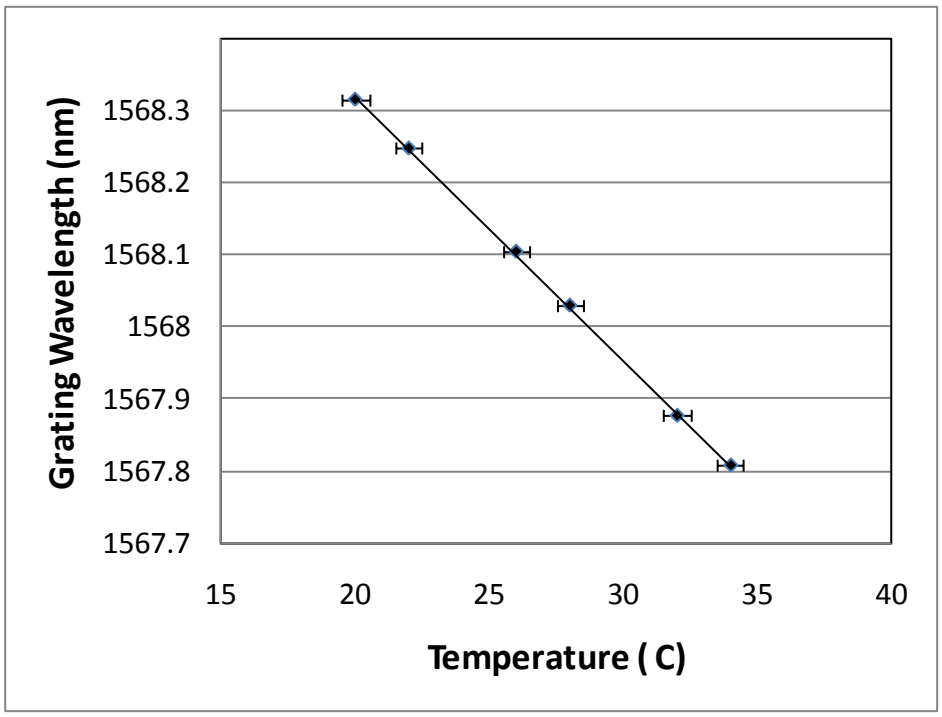

Reflected Power (dBm)
-50
-55
-60
-65
-70
-75
-80
-85
-90
1540
1550
1560
1570
1580
Wavelength (nm)

Figure 4


Grating Wavelength (nm)
1568.3
1568.2
1568.1
1568
1567.9
1567.8
1567.7
15
20
25
30
35
40
Temperature (C)

1 Xiong, Z., Peng, G., Wu, B., and Chu, P.: 'Highly tunable Bragg gratings in single-mode polymer optical fibers', IEEE Photonics Technology Letters, 1999, 11, (3), pp. 352-354
2 Brandrup, J.: 'Polymer Handbook' (Wiley, 1999. 1999)
3 Aressy, M.: 'Manufacturing optimisation and mechanical properties of polymer optical fibre'. MPhil, Birmingham University, 2006
4 Dobb, H., Webb, D.J., Kalli, K., Argyros, A., Large, M.C.J., and van Eijkelenborg, M.A.: 'Continuous wave ultraviolet light-induced fiber Bragg gratings in few- and single-mode microstructured polymer optical fibers', Optics Letters, 2005, 30, (24), pp. 3296-3298
5 Peng, G.D., and Chu, P.L.: 'Polymer optical fiber photosensitivities and highly tunable fiber gratings', Fiber and Integrated Optics, 2000, 19, pp. 277-293
6 Emiliyanov, G., Jensen, J.B., Bang, O., Hoiby, P.E., Pedersen, L.H., Kjaer, E.M., and Lindvold, L.: 'Localized biosensing with Topas microstructured polymer optical fiber', Optics Letters, 2007, 32, (5), pp. 460-462
7 Emiliyanov, G., Jensen, J.B., Bang, O., Hoiby, P.E., Pedersen, L.H., Kjaer, E.M., and Lindvold, L.: 'Localized biosensing with Topas microstructured polymer optical fiber: Erratum', Optics Letters, 2007, 32, (9), pp. 1059
8 www.topas.com
9 Zhang, C., Zhang, W., Webb, D.J., and Peng, G.D.: 'Optical fibre temperature and humidity sensor', Electronics Letters, 2010, 46, (9), pp. 643-644
10 Nielsen, K., Rasmussen, H.K., Adam, A.J.L., Planken, P.C.M., Bang, O., and Jepsen, P.U.: 'Bendable, low-loss Topas fibers for the terahertz frequency range', Optics Express, 2009, 17, (10), pp. 8592-8601
11 Webb, D.J., Kalli, K., Zhang, C., Komodromos, M., Argyros, A., Large, M., Emiliyanov, G., Bang, O., and Kjaer, E.: 'Temperature sensitivity of Bragg gratings in PMMA and TOPAS microstructured polymer optical fibres - art. no. 69900L'. Photonic Crystal Fibers II2008 pp. L9900-L9900
12 Webb, D.J., and Kalli, K.: 'Polymer fibre Bragg gratings', in Cusano, A. (Ed.): 'Fiber Bragg Grating Sensors: Thirty Years from Research to Market' (Bentham eBooks, 2010)